Minnesota Renewable Energy Integration and Transmission Study

MN Laws 2013, Omnibus Energy Bill, Article 12, Section 4

Bill Grant
Deputy Commissioner, Commerce DER

Matt Schuerger
Technical Advisor to Commerce DER

Saint Paul, Minnesota
September 13, 2013

division of energy resources
Minnesota Department of Commerce

Overview

- Background & Process
  - Legislation, Schedule, Participants
- Integration of Variable Renewable Generation into the Grid
  - Characteristics – variability and uncertainty
  - Operating impacts, Forecasting, Capacity value, Flexibility
- Minnesota / Regional Work
  - MN Wind Integration Studies, Dispersed Renewable Generation Studies, Renewable Energy Standard Transmission Studies
  - MISO Wind Integration
- Wind Integration Studies
  - Key Findings
- Current Integration Study
  - Objectives
  - Key Questions & Issues
  - Study Approach & Structure

Additional Material: References/Sources

division of energy resources
Minnesota Department of Commerce

MN RE Integration and Transmission Study

Minnesota Laws 2013, Chapter 85, Article 12, Sec. 4

- The MN utilities and transmission companies, in coordination with MISO, will do the engineering study;
- The Department will direct the study and will appoint and lead a Technical Review Committee (TRC)
- It will be an engineering study of increasing the RES to 40% by 2030, and to higher proportions thereafter, while maintaining system reliability; The study must incorporate and build upon prior study work;
- The final study will be completed by November 1, 2014 and must include: 1) A conceptual plan for transmission for generation interconnection and delivery and for access to regional geographic diversity and regional supply and demand side flexibility, and 2) Identification and development of potential solutions to any critical issues encountered.

MN RE Integration and Transmission Study

Minnesota Laws 2013, Chapter 85, Article 12, Sec. 4

Schedule

- **June – August 2013:** The Department reviewed prior and current studies and worked with stakeholders and study participants to identify key issues, began development of a draft technical study scope, and accepted recommendations of qualified Technical Review Committee (TRC) members;
  - **Many thanks for the numerous TRC nominations and study scope comments that have been submitted to the Department**
- **September 2013:** The Department will finalize the study scope and schedule and will appoint the TRC;
- **October 2013 – October 2014:** The study will be completed.

division of energy resources
Minnesota Department of Commerce

MN RE Integration and Transmission Study

Minnesota Laws 2013, Chapter 85, Article 12, Sec. 4

Scoping Participants

- Stakeholders, Commerce, MN Utilities & Transmission Companies, MISO, National Experts

Study Participants

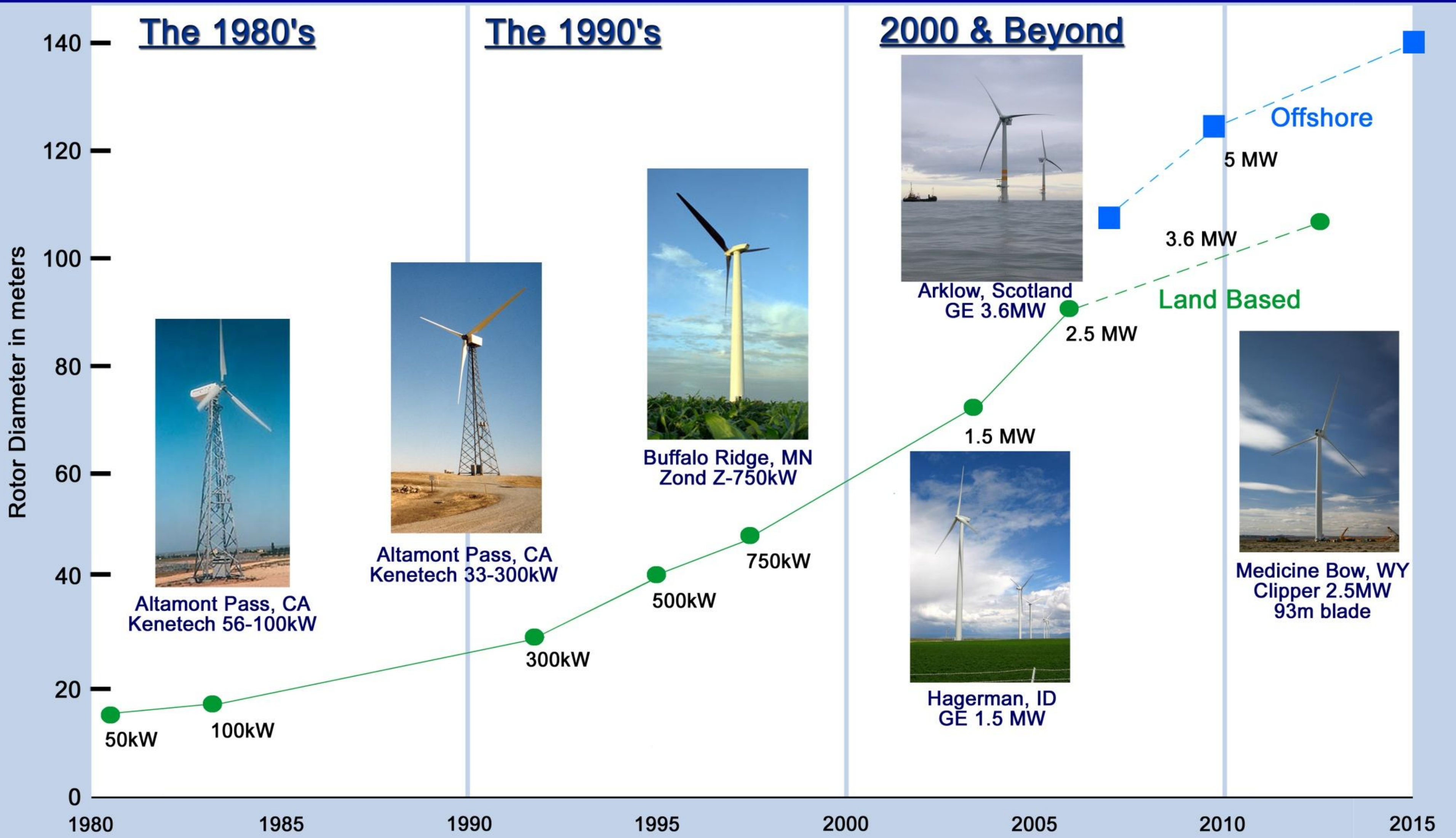
- MN Utilities and Transmission Companies; in Coordination with MISO
- Under the direction of the Minnesota Department of Commerce Division of Energy Resources
- Technical Review Committee
  - Expertise in electric transmission system engineering, electric power system operations, & renewable energy generation technology
  - Will review study's proposed methods and assumptions, ongoing work, and preliminary results

division of energy resources
Minnesota Department of Commerce

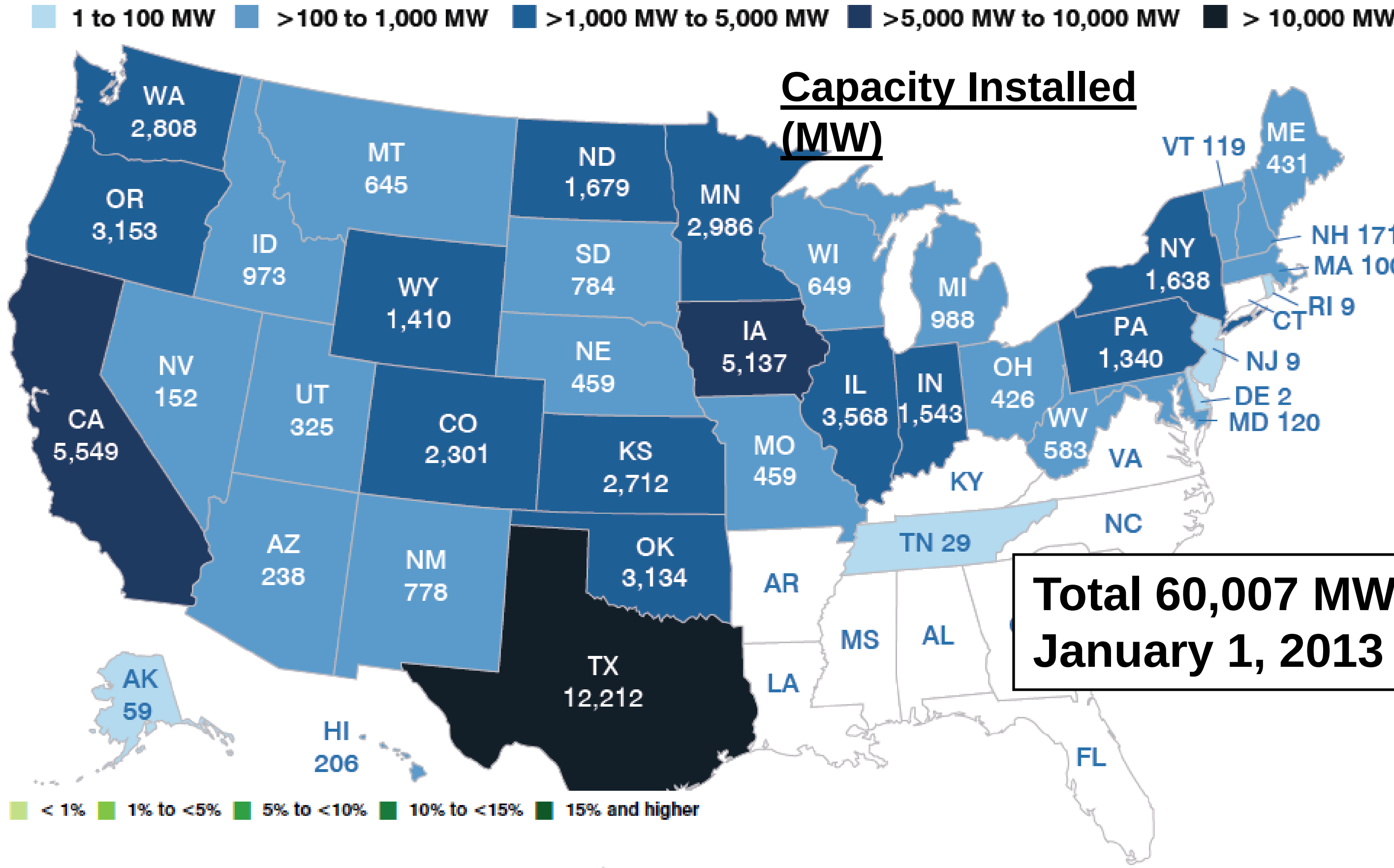
Integration of Variable Renewable Generation into the Grid

division of energy resources
Minnesota Department of Commerce

Evolution of U.S. Commercial Wind Technology

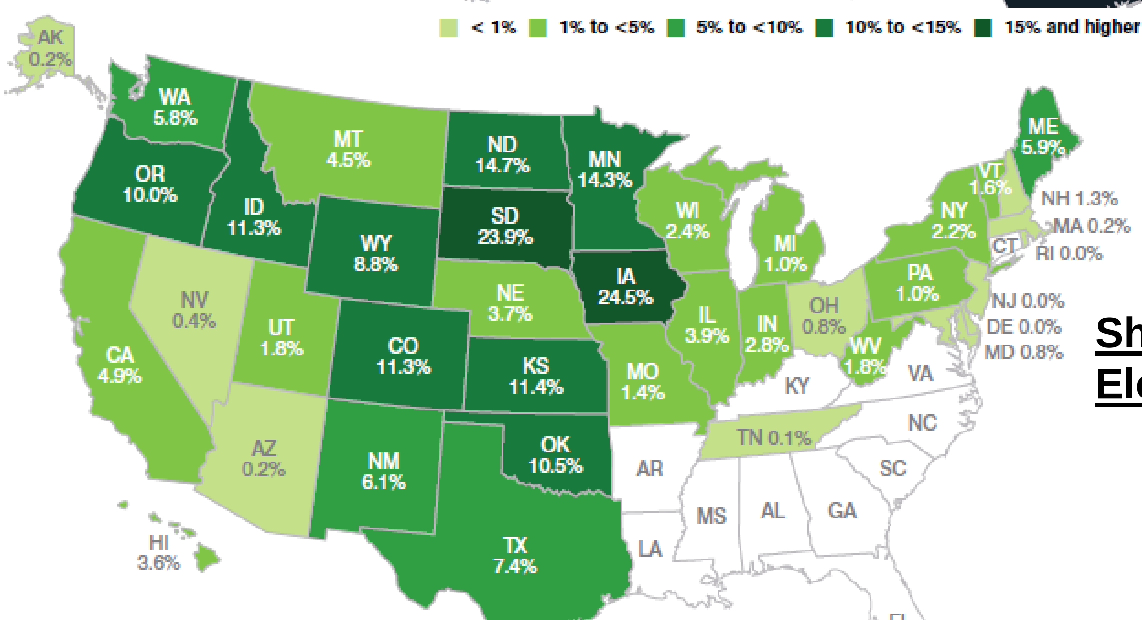


Current U.S. Wind Power



Capacity Installed (MW)

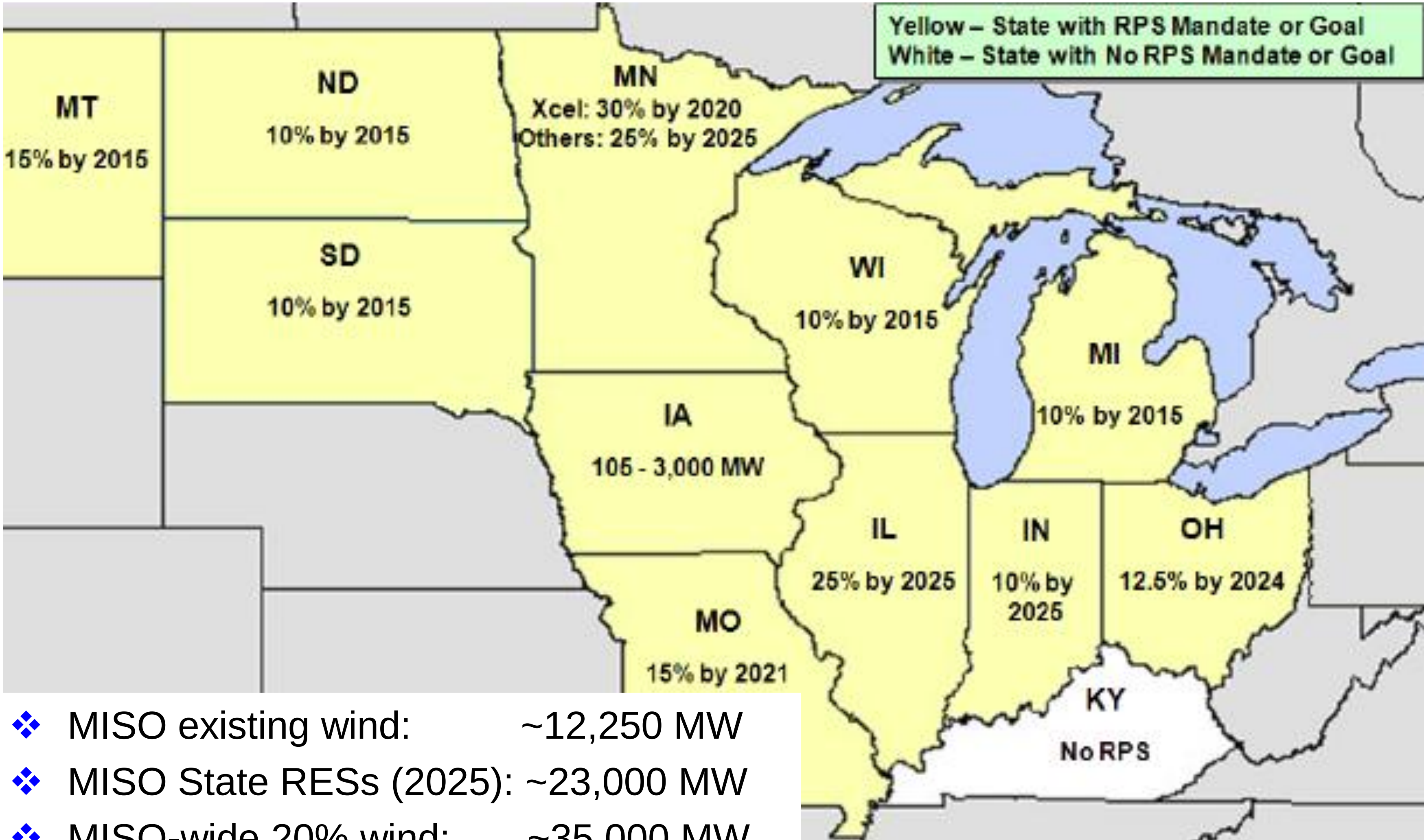
Total 60,007 MW
January 1, 2013



Share of Annual Electricity Generation

Source: American Wind Energy Association

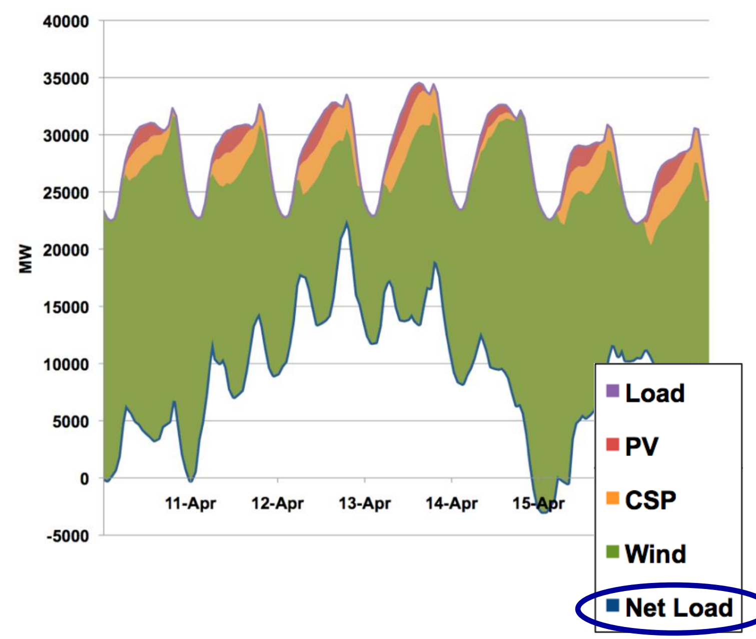
MISO State RES Requirements (June 2011)



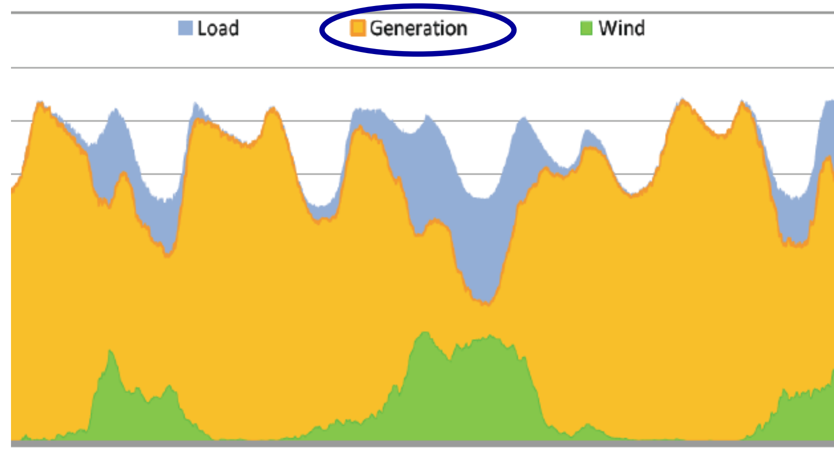
- MISO existing wind: ~12,250 MW
- MISO State RESs (2025): ~23,000 MW
- MISO-wide 20% wind: ~35,000 MW

Variability and Uncertainty - *Net Load*

- Power system operators are constantly faced with variability and uncertainty
  - Load and regional imports/exports vary by seconds, minutes, hours, by day and with weather; may not be what it was forecast to be
  - In real time operations, the system must respond to the *net load* including both expected and unexpected variations
  - Variable generation adds to the net load variability and uncertainty
- Increasing net load variability & uncertainty will drive a need for more flexible resources (supply and demand side)



Source: WWIS, NREL / GE Energy. 2010

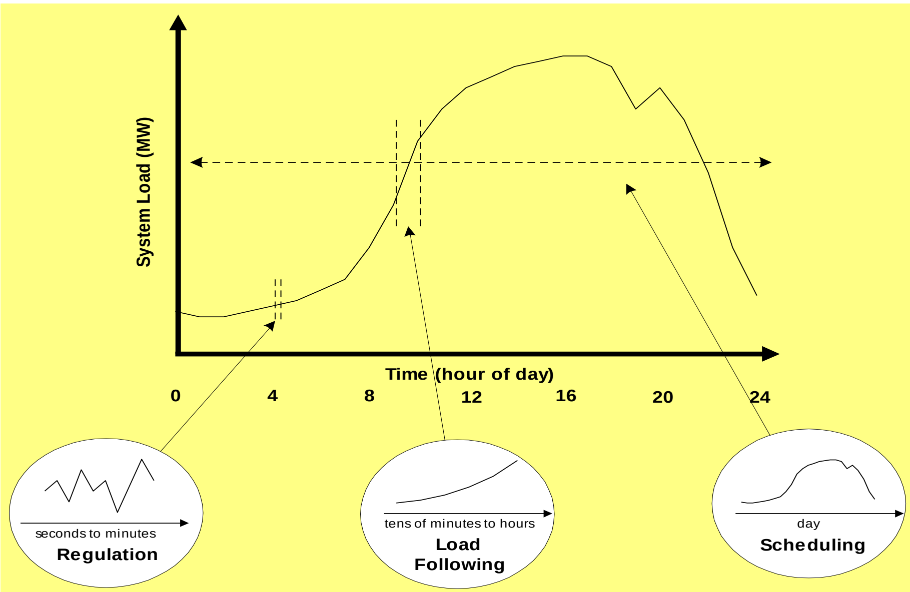


Source: MISO. 2011

division of energy resources
Minnesota Department of Commerce

Power System Operation Impacts

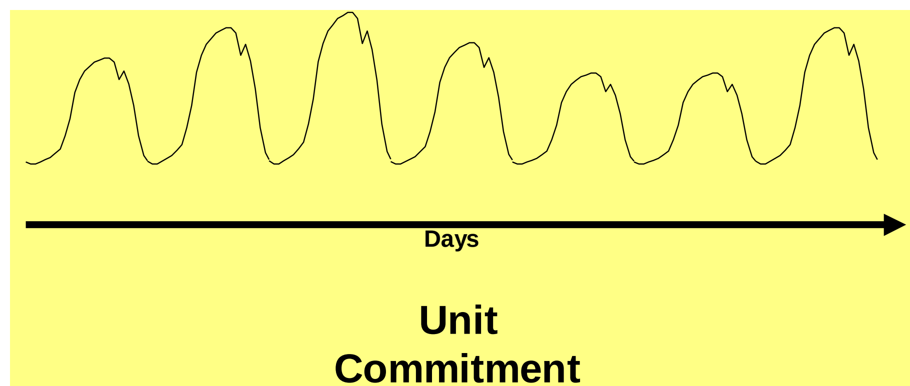
Time Scales of Interest:



- **Regulation** -- seconds to a few minutes -- similar to variations in customer demand

- **Load-following** -- tens of minutes to a few hours -- usage follows predictable patterns

- **Scheduling and commitment of generating units** -- one to several days



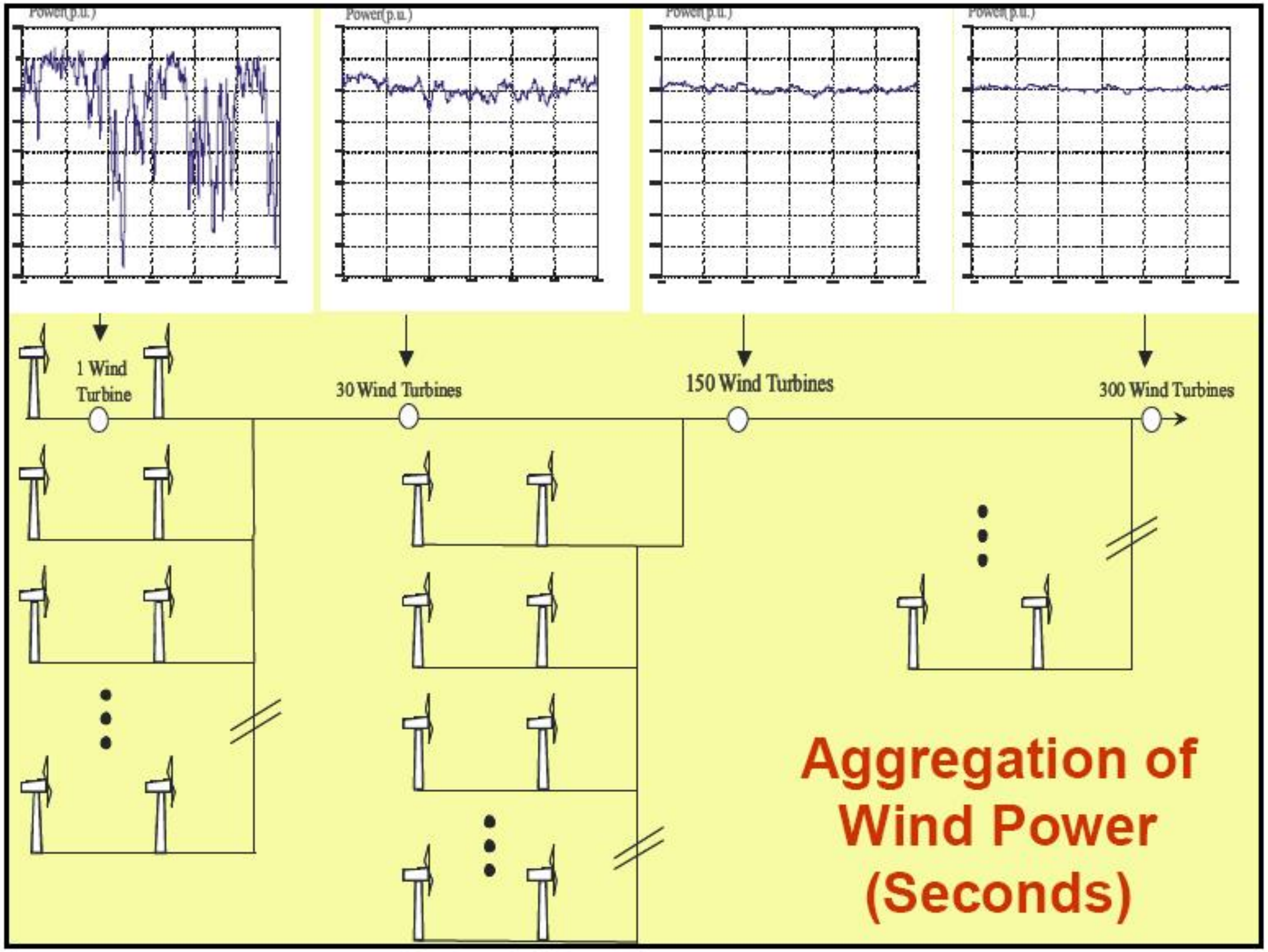
division of energy resources
Minnesota Department of Commerce

Power System Operation Impacts

- **Regulation**: *Can wind plants affect or increase the area control error (ACE)?*
- **Load following**: *What happens if wind plant output decreases in the morning when the load is increasing?*
- **Scheduling**: *How can committed units be scheduled for the day if wind plant output is not predicted? What happens if the wind forecast is inaccurate?*
- **Committing generating units**: *Over several days, how should wind plant production be factored planning generation units that need to be available?*
- **Market Operations:** *How do large amounts of wind generation affect regional energy markets? Does congestion result?*

division of energy resources
Minnesota Department of Commerce

The Power of Aggregation

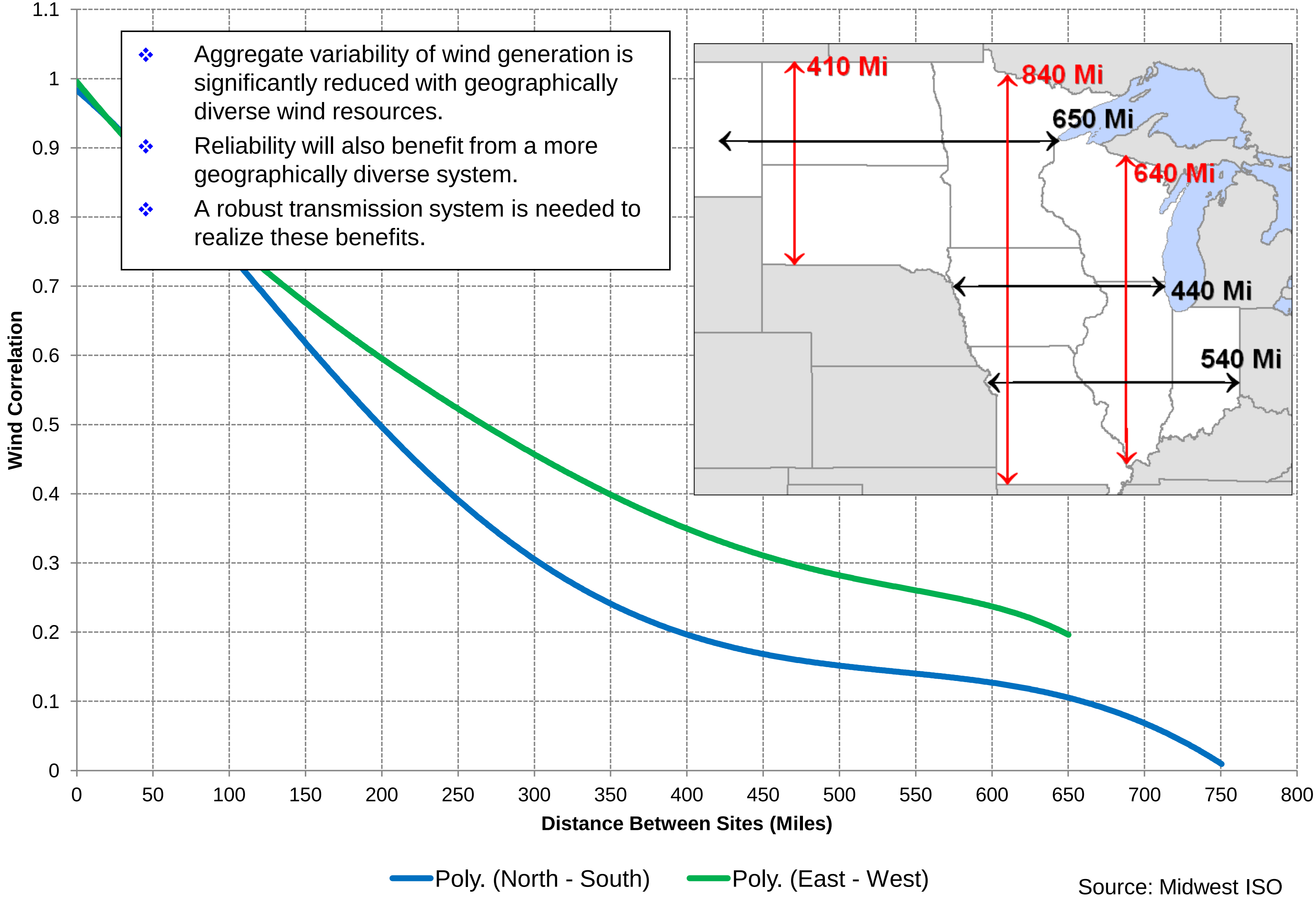


Source: Thomas Ackermann, Energynautics

division of energy resources
Minnesota Department of Commerce

Wind Correlation vs Distance - MISO RGOS Study Area

- Aggregate variability of wind generation is significantly reduced with geographically diverse wind resources.
- Reliability will also benefit from a more geographically diverse system.
- A robust transmission system is needed to realize these benefits.



Source: Midwest ISO

Forecasting Technology & Results

- Modern wind power forecasting includes advanced physical and "learning system" methods
  - Multiple forecast models (ensemble methods for both accuracy & uncertainty)
  - Computational Learning Systems (adaptive adjustment based on actual performance)
  - Smart persistence (takes advantage of current conditions approaching real time)
- Representative results for individual & regionally aggregated wind plants:

	Single Plant	Large Region
Hour Ahead	Forecast Error	
Energy (% actual)	10-15%	6-11%
Capacity (% rated)	4-6%	3-6%
Day Ahead		
Hourly Energy (% Actual)	25-30%	15-18%
Hourly Capacity (% Rated)	10-12%	6-8%

- When aggregated on a system-wide basis, errors are substantially reduced (30 – 50% in forecast error depending on size of region)

division of energy resources
Minnesota Department of Commerce

Sources: UWIG 2012; WindLogics

Capacity Value – Wind Generation

- Measure of relative plant contributions to reliability in the context of overall system reliability
- Wind is primarily an energy resource, but does make a small contribution to planning reserves
- Depends on timing of wind energy vs. load characteristics
- Various uses for capacity value
- Effective Load Carrying Capability (ELCC)
  - Increase in load that can be supported with a new generator while holding the system reliability constant (fixed LOLE – Loss of Load Expectation)
  - Data-driven, empirical approach based on hourly load profiles & actual generator unit data
- From a NERC perspective, capacity value for land-based wind power is typically calculated at between ~10% & 20% of nameplate

division of energy resources
Minnesota Department of Commerce

Minnesota Wind Integration Studies – key findings

2004 Xcel Wind Integration Study

The 2003 MN Legislature adopted a requirement for an Independent Study of the impacts of over 825 MW of wind power on the Xcel system

- 1500 MW of wind generation on the Xcel system in 2010 results in an increase in scheduling and unit commitment costs, under a conservative application of operation practices & markets, of $4.37/MWh of wind generation
- Costs impacts could be reduced with improved strategies and practices for unit commitment and scheduling, improved forecasting, and improved markets

2006 Minnesota Wind Integration Study

The 2005 MN Legislature adopted a requirement for a Wind Integration Study of the of the impacts of increasing wind to 20% of MN retail electric energy sales

- **The addition of wind generation to supply 15%, 20%, & 25% of MN retail electric energy sales can be reliably accommodated by the electric power system**
- The total integration operating cost for up to 25% wind energy delivered to Minnesota customers is less than $4.50 per MWh of wind generation.

  Key drivers include:

  - A geographically diverse wind scenario;
  - The large MISO energy market;
  - Functional consolidation of balancing authorities;
  - Sufficient transmission.

division of energy resources
Minnesota Department of Commerce

Minnesota Renewables Transmission Studies

2008 & 2009 MN Dispersed Renewable Generation (DRG) Studies

The 2007 MN legislature adopted a requirement for the MN utilities to analyze the transmission impacts of 1200 MW new dispersed renewable generation (aggregated from wind plants of 10 to 40 MW each) located throughout MN.

- DRG I: The analysis successfully demonstrated a scenario where an initial 600 MW of DRG could be sited; **Found that even dispersed generation can have substantial impacts on the electric grid**.
- DRG II: The analysis showed that an additional 600 MW of DRG is only possible with additional transmission upgrades; **Found limited "free" DRG opportunities**.

2007 MN Renewable Energy Standard Transmission Study 2009 MN RES Update, Corridor, & Capacity Validation Studies

The 2007 MN Legislature adopted a requirement for the MN utilities to develop plans for transmission needed to meet the RES milestones

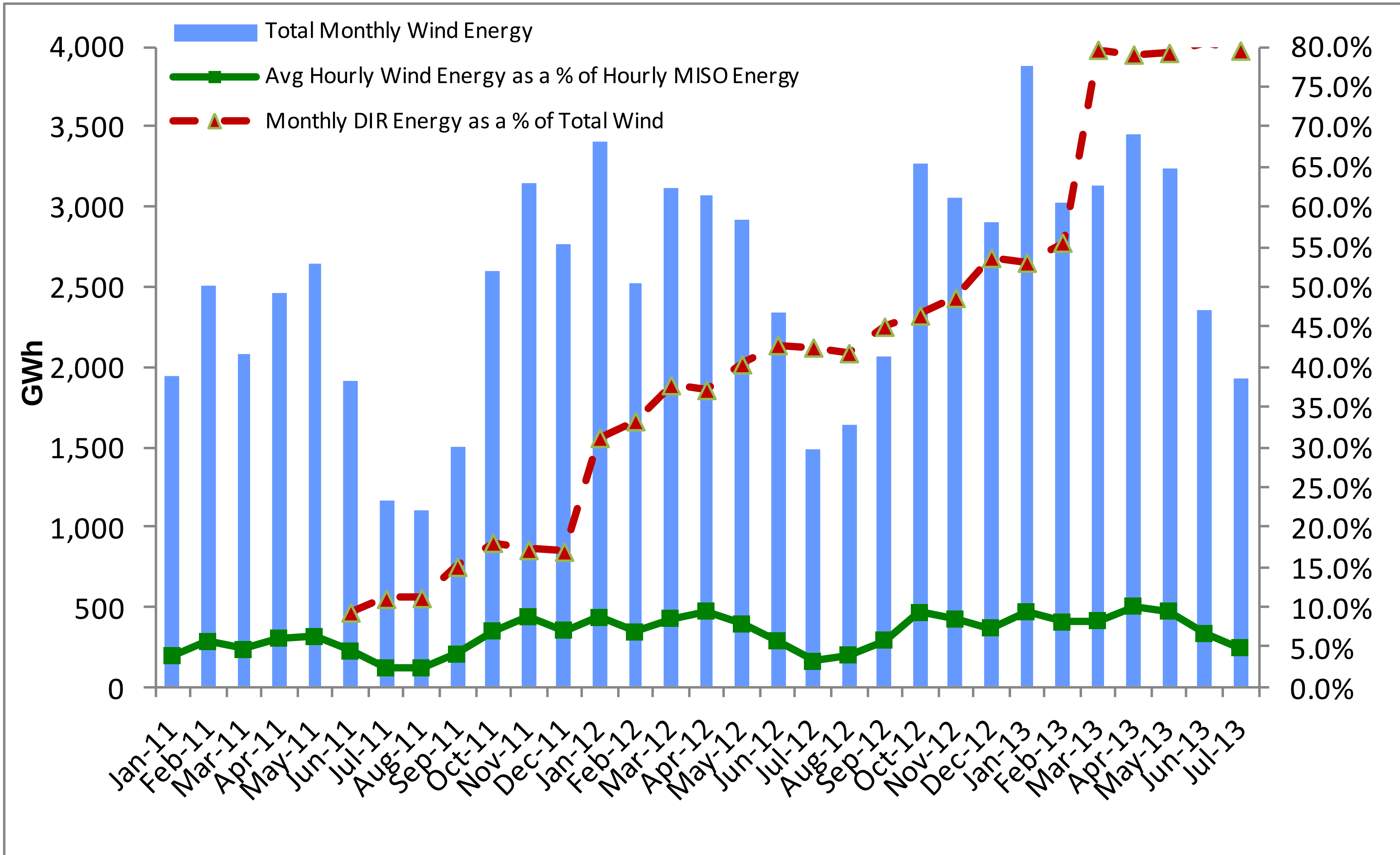
- Initial Report (Nov 2007) included: an assessment of the RES milestones ("Gap Analysis"), review of transmission studies, conceptual transmission plans, specific line proposals, a five year action plan, and critical issues
- Technical Reports (March 2009) included: *The Southwest Twin Cities to Granite Falls Transmission Upgrade Study* ("Corridor"), *MN RES Transmission Update Study*, and the *Capacity Validation Study*

Wind Integration in MISO

- **Wind generation has increased ten-fold in five years**
  - Installed wind capacity: 12,240 MW (July 2013);
    9,543 MW is registered as DIR
  - Record wind peak: 10,012 MW (Set 11/23/12; ~25% of gen output at the time)
  - Wind generation: 6.8% of total MISO energy over the last 12 months
    (Aug12-Jul13; percent of MISO RT load)
  - Congestion is increasing; MVP lines will help mitigate
- **MISO operations has gained significant experience successfully integrating wind**
  - Wind helps keep prices low for MISO customers and the end-user consumer
  - Output variability is being mitigated by geographic diversity
  - Wind forecasting has improved and is expected to continue improving
  - Wind has had a small impact on regulation reserves
    Contingency reserves have never been deployed due to a drop in wind output
  - Wind contributes to peak load (2013 capacity value: fleet 13.3%, LRZ1 15.2%)
- **Market rules are evolving**
  - DIR implemented; Ramp Management under development

Sources: MISO Info Forum 8/20/13, Management Presentation to BOD (Markets Committee) 2/15/12; MISO 11/27/12

Wind Generation - MISO



division of energy resources
Minnesota Department of Commerce

Source: MISO, Informational Forum, 8/20/13

Dispatchable Intermittent Resources (DIR) - MISO

- Benefits of DIRs in Real-Time operations
  - Improved market efficiency through economic dispatch and better price signals
  - Improved system reliability through better congestion management by replacing manual curtailments with automated real-time dispatch
  - Wind generation is a full participant in the market (offers day ahead, forecasts day ahead and operating hour, dispatches in real time)

- DIR Status (Aug 2013)
  - ~80% wind capacity in MISO is dispatchable (DIR)

- Wind curtailment is now dominated by economic/reliability dispatch (SCED) down of DIR; curtailments to date have been largely due to transmission congestion
  - In total, ~2.7% of available wind energy was curtailed in 2012; Manual wind curtailments in 2012 trend down as wind fleet transitioned to DIR
    - ~0.9% of total wind energy available was manually curtailed in 2012
    - Wind curtailment due to DIR dispatch down was ~1.8% of total available wind energy in 2012

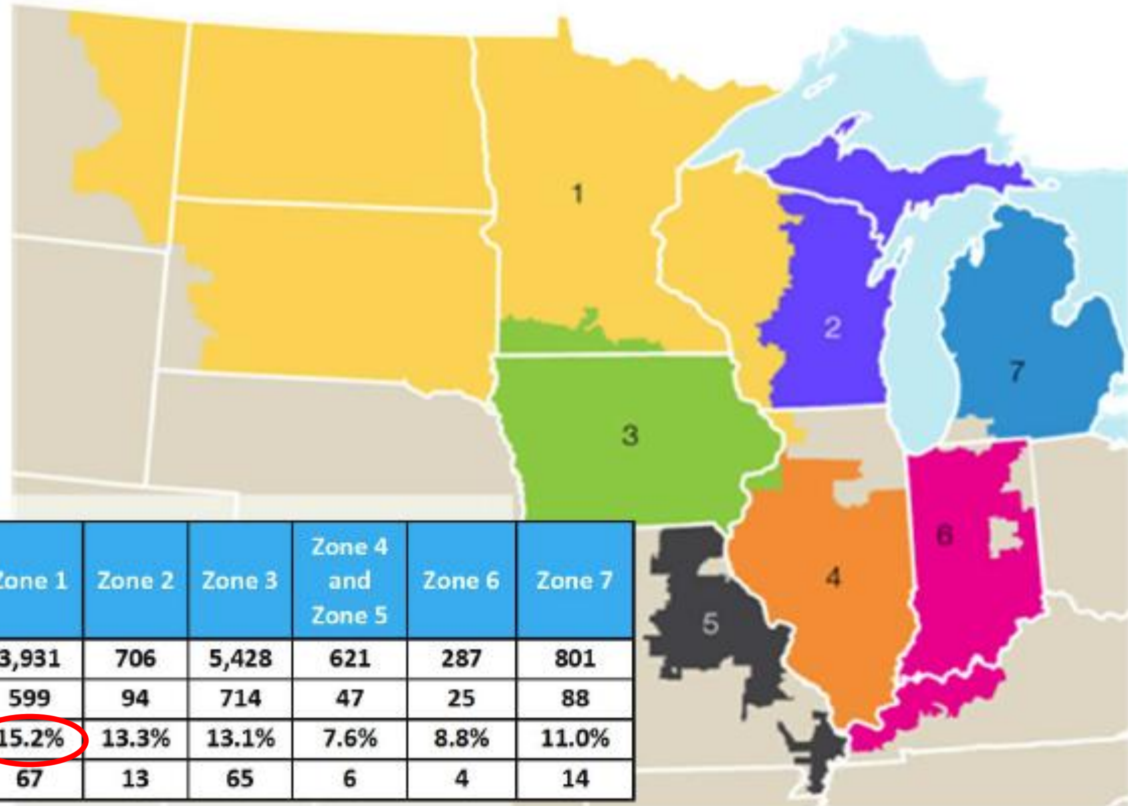
division of energy resources
Minnesota Department of Commerce

Sources: MISO MSC 3/05/13, Info Forum 8/20/13

Wind Capacity Value – MISO 2013 LOLE Study

- Planning Year 2013 Wind Capacity Credit
  - MISO system-wide 13.3% of Registered Maximum MW

- Distribution of Wind Capacity by MISO Local Resource Zones



Metric	MISO	Zone 1	Zone 2	Zone 3	Zone 4 and Zone 5	Zone 6	Zone 7
Registered Max (MW)	11,774	3,931	706	5,428	621	287	801
UCAP (MW)	1,567	599	94	714	47	25	88
ELCC %	13.3%	15.2%	13.3%	13.1%	7.6%	8.8%	11.0%
Wind CPnode count	169	67	13	65	6	4	14

- Methodology: Full ELCC (NERC IVGTF & IEEE Task Force recommendations)

division of energy resources
Minnesota Department of Commerce

Sources: MISO LOLE WG Nov 2012 & West SPM 12/10/12

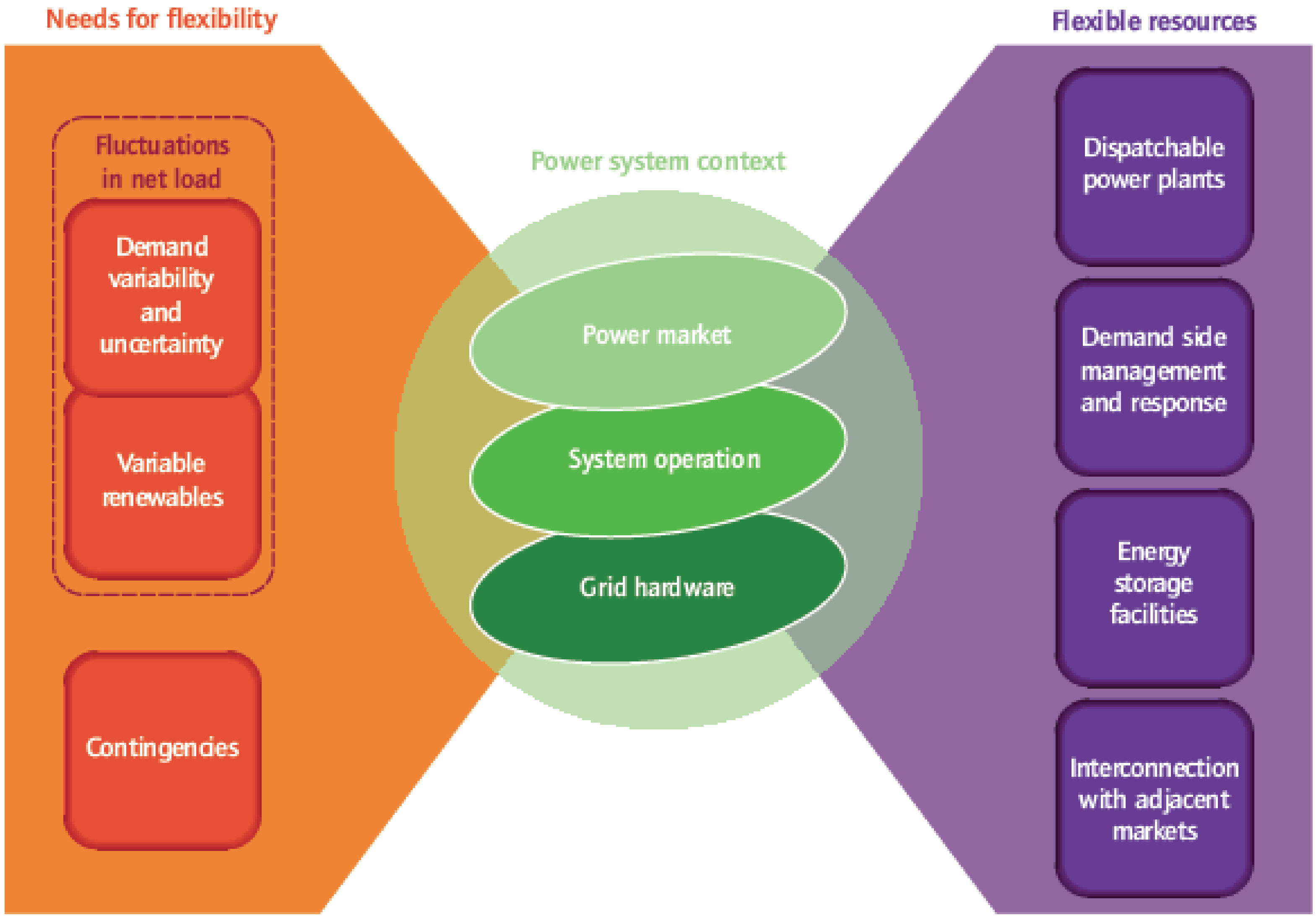
Related Work In Progress

- DOE Wind Vision Study
  - State of the wind industry, targets, impacts, roadmap
  - Started: May 2013; Scheduled completion: June 2014
- NREL Eastern Renewable Generation Integration Study (ERGIS)
  - Determine operational impact of 30% wind and solar on the Eastern Interconnection at a sub-hourly level; Evaluate options to mitigate impacts of variability and uncertainty
  - Started: September 2011; Scheduled completion: June 2014
- NERC Integration of Variable Generation Task Force (IVGTF)
- IEEE Wind and Solar Power Coordinating Committee

NERC Integration of Variable Generation Task Force (IVGTF)

- 1.1 *Standard Models for Variable Generation*. May 2011
- 1.2 *Methods to Model and Calculate Capacity Contributions of Variable Generation for Resource Adequacy Planning*. March 2011
- 1.3 *Interconnection Requirements for Variable Generation*. Sept 2012
- 1.4 *Flexibility Requirements and Metrics for Variable Generation: Implications for Planning Studies*. August 2010
- 1.5 *Potential Reliability Impacts of Emerging Flexible Resources*. Nov 2010
- 1.6 *Probabalistic Methods for Variable Generation*. In Development
- 1.7 *Reconciling Existing LVRT (e.g. FERC Order 661-A) and IEEE Requirements (e.g. Std 1547).* In Development
- 1.8 *Potential Reliability Impacts of Distributed Resources*. August 2011
- 2.1 *Variable Generation Power Forecasting for Operations*. May 2010
- 2.3 *Ancillary Service and Balancing Authority Area Solutions to Integrate Variable Generation*. March 2011
- 2.4 *Operating Practices, Procedures, Tools*. March 2011
- 3.1 *Reference Manual*. In Development

The Balancing Challenge – International Energy Agency (IEA)



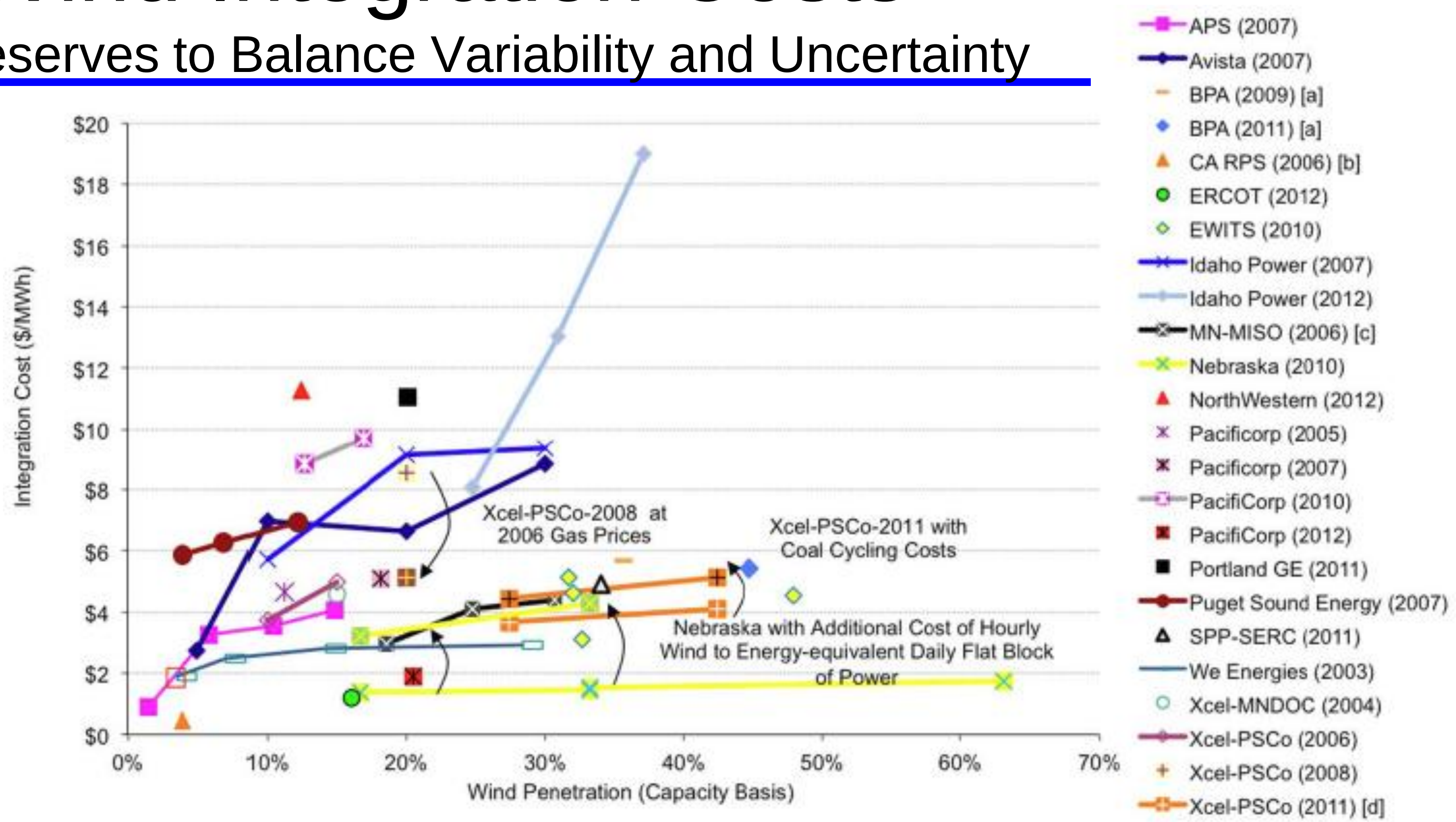
Sources: Aidan Touhy, EPRI; *Harnessing Variable Renewables. IEA. 2011.*

Flexibility

- **Sources of flexibility include:**
  - Dispatchable plants, demand side resources, grid / interconnections, and storage
- The extent to which existing flexible resources are actually available and used varies widely
  - Some regions not only have large amounts of flexible resources but are also more likely to make those resources available for balancing
- **Key power system characteristics which affect whether technical flexibility is available include: grid strength, market size, scheduling / dispatch speed, use of forecasting, and value of flexibility in the market**
  - After existing flexibility is made available, it may be necessary to increase the flexible resources through removal of barriers and development of incentives
  - Will need to provide incentives to fully engage flexibility from the supply side (both conventional and renewable), the demand side, interconnections / grid, and storage.
- Market rules are evolving to improve system flexibility including:
  - Improved system scheduling / dispatch
  - Improved procurement / payment of ancillary services
  - Incentives for load following / ramp management
  - Markets are increasingly incorporating dispatch of wind generation

U.S. Wind Integration Costs

Cost of Reserves to Balance Variability and Uncertainty



Source: *2012 Wind Technologies Market Report*, Ryan Wiser & Mark Bolinger, DOE LBNL, Aug. 2013

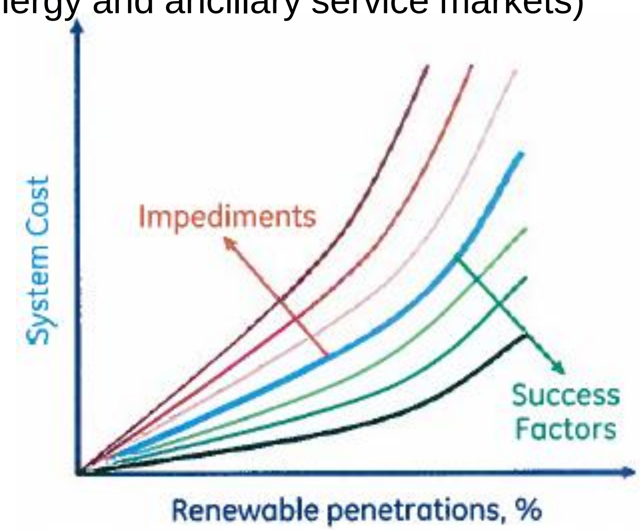
Key overall study findings include:

- Integration cost is difficult or impossible to calculate correctly;
- Other resources have integration costs;
- Increasing interest in assessing system cost, not just integration cost.

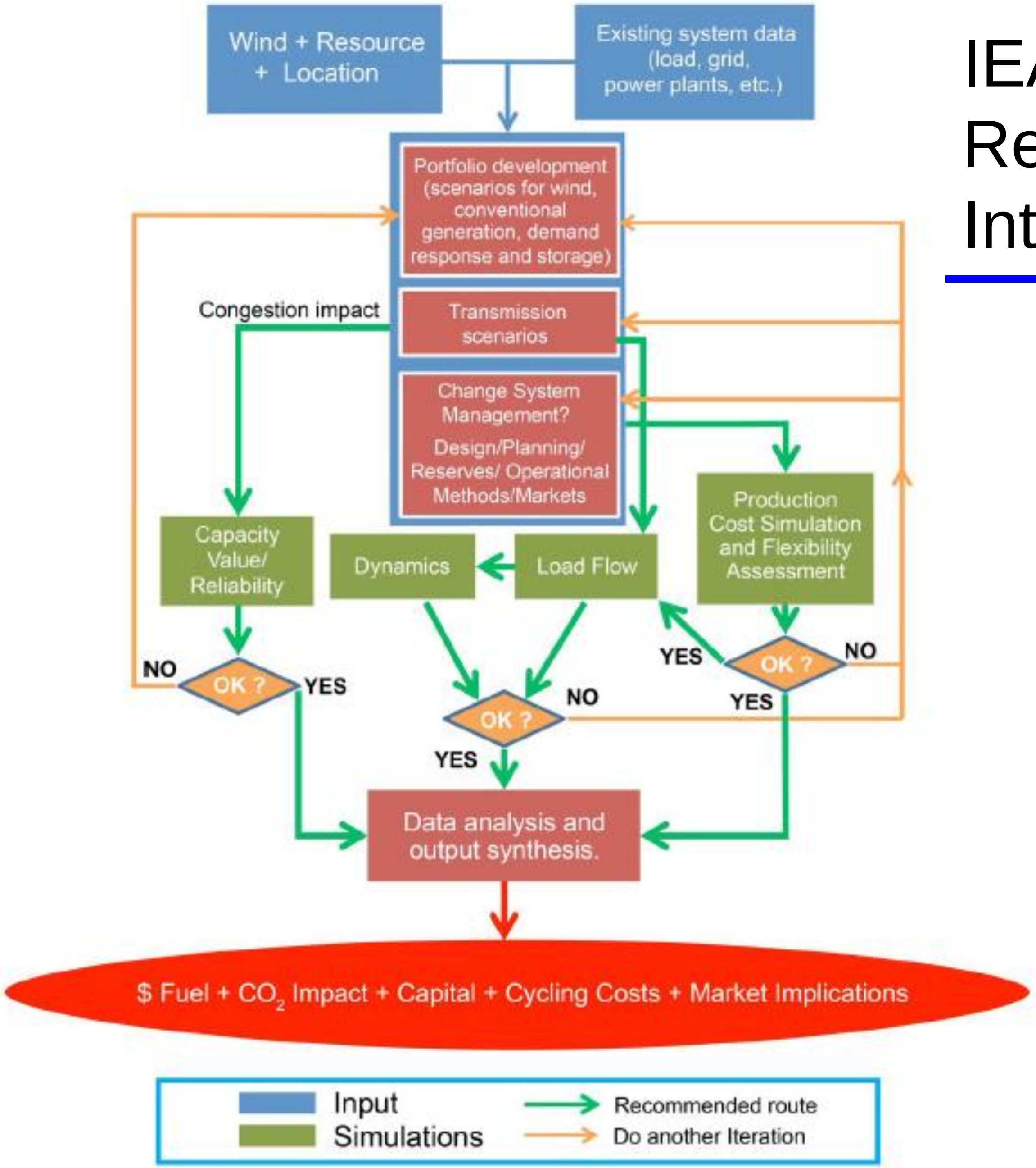
division of energy resources
Minnesota Department of Commerce

Integration Study – Key Findings

- Variable Energy Resources (wind, solar) add variability and uncertainty to the power system over seconds, minutes, and hours
- **Integration is challenging when there is:**
  - Lack of transmission
  - Lack of balancing area cooperation
  - Inflexibility due to market rules, contracts, etc
  - Inflexible operating strategies during light load and high risk periods
  - Unobservable distributed generation (behind the meter)
- **Wind and solar integration impacts are significantly reduced with:**
  - Large balancing areas with a strong grid (captures significant benefits to diversity -geographic, resource, load; enables access to the physical flexibility that exists in the regional power system)
  - Large, liquid, fast markets (sub-hourly, co-optimized energy and ancillary service markets)
  - Forecasting wind generation (significantly reduces uncertainty and costs)
  - Spatial diversity
  - Grid-friendly renewables (frequency ride through, real and reactive power control, etc)
  - Responsive conventional fleet (higher quick-starts, deeper turn-down, faster ramps)



Source: General Electric Company



IEA Task 25 - Recommendations for Integration Studies

- A complete study with all links between phases
- Most studies only analyze part of the impacts

Source: *IEA Expert Group Report on Recommended Practices for Wind Integration Studies,* May 2013; H. Holttinen presentation April 2013.

MN RE Integration and Transmission Study

Minnesota Laws 2013, Chapter 85, Article 12, Sec. 4

division of energy resources
Minnesota Department of Commerce

MN RE Integration and Transmission Study

Minnesota Laws 2013, Chapter 85, Article 12, Sec. 4

Objectives

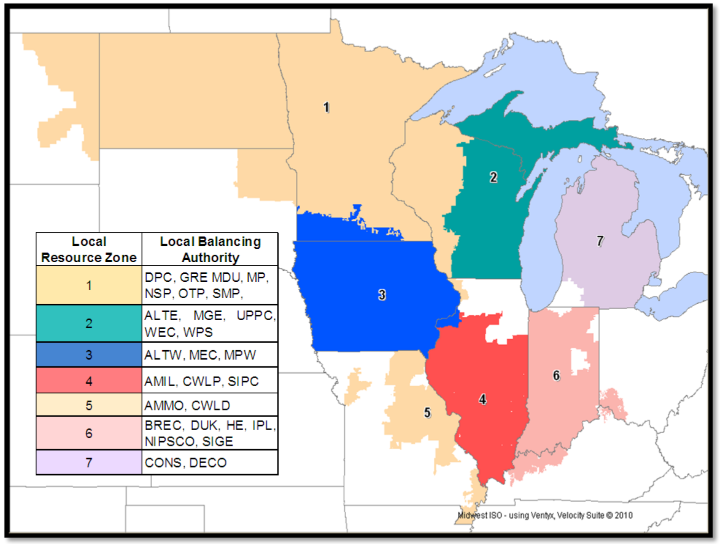
1. Evaluate the impacts on reliability and costs associated with increasing renewable energy to 40% of Minnesota retail electric energy sales by 2030, and to higher proportions thereafter;
2. Develop a conceptual plan for transmission necessary for generation interconnection and delivery and for access to regional geographic diversity and regional supply and demand side flexibility;
3. Identify and develop options to manage the impacts of the variable renewable energy resources;
4. Build upon prior renewable energy integration studies and related technical work;
5. Coordinate with recent and current regional power system study work;
6. Produce meaningful, broadly supported results through a technically rigorous, inclusive study process.

Study Region

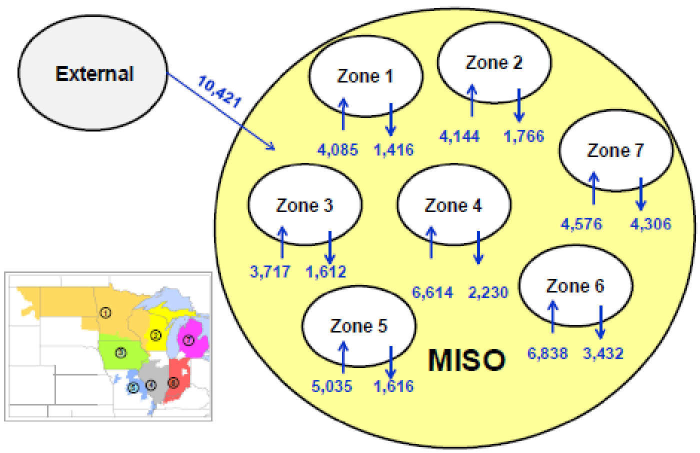
- **MN retail electric sales**
  - Annual energy sales: 65,436.7 GWh (2011)

	2011 MN Retail Sales in MWh[1]	
Investor-Owned Utilities		
Xcel	31,788,268	48.6%
MP	10,130,969	15.5%
OTP	2,085,902	3.2%
IPL	846,818	1.3%
NWEC	450	0.0%
TOTAL IOU	44,852,407	68.5%
Cooperative Utilites		
GRE	10,597,425	16.2%
Minnkota	1,542,022	2.4%
Dairyland	787,874	1.2%
Basin	1,798,175	2.7%
TOTAL COOP	14,725,496	22.5%
Municipal Utilities		
SMMPA	2,929,414	4.5%
MRES	1,226,901	1.9%
MMPA	1,382,808	2.1%
CMMPA	319,698	0.5%
TOTAL MUNI	5,858,821	9.0%
TOTAL ALL	65,436,724	100.0%

[1] http://mn.gov/commerce/energy/images/2013RESLegReport.pdf



- MISO
  - Annual energy sales: 497.8 TWh (8/12-7/13)
  - Peak demand: 98,576 MW (July 2012)



division of energy resources
Minnesota Department of Commerce

Key Questions & Issues

1. Renewable generation to be studied?

How much (MW); Where (e.g. wind, PV, biomass resources, interconnection queues, proposed projects, etc); What type (e.g. transmission connected / distribution connected)? What are the technical and economic characteristics of the projected renewable generation? How many penetration levels should be studied?

- Minnesota future wind, solar, biomass sited MN-centric (MN, ND, SD)?
- MISO future wind & solar sited per MTEP (e.g. expanded RGOS zones)?
- Use existing wind and solar hourly data sets (e.g. NREL)?
- Incorporate wind and solar forecasting

Retail Sales Annual Growth Rate	Total RE Percent Retail Sales	Variable RE: Wind Percent Retail Sales	Variable RE: PV Percent Retail Sales	2013	2020		2025		**2030**		**2040**		**2050**	
0.5%	MN Retail Sales (GWh)			66,093	68,441		70,169		71,941		75,620		79,487	
				Wind MW	Wind MW	PV MWdc	Wind MW	PV MWdc	Wind MW	PV MWdc	Wind MW	PV MWdc	Wind MW	PV MWdc
Minnesota	16%	16%		3,177										
	27.5%	*26.5%*	*1%*		*5,176*	*521*	*5,307*	*534*	*5,441*	*547*	*5,719*	*575*	*6,011*	*605*
	40%	**37%**	**3%**						**7,235**	**1,449**	**7,605**	**1,523**	7,994	1,601
	50%	**40%**	**10%**								**8,221**	**5,078**	8,642	5,338
	60%	45%	15%										9,722	8,006
	80%	60%	20%										12,963	10,675
0.75%	MISO Retail Sales (TWh)			498	525		544		565		609		656	
				Wind MW	Wind MW	PV MWdc	Wind MW	PV MWdc	Wind MW	PV MWdc	Wind MW	PV MWdc	Wind MW	PV MWdc
MISO	7%	7%		12,431										
	14.0%	*13.5%*	*0.5%*		*23,096*	*2,303*	*23,975*	*2,391*	*24,888*	*2,482*	*26,818*	*2,674*	*28,899*	*2,882*
	20%	**19%**	**1%**						***33,134***	***4,302***	***35,704***	***4,635***	38,474	4,995
	25%	**22%**	**3%**								***41,342***	***13,906***	44,549	14,985
	30%	25%	5%										*50,624*	*24,974*

MN Renewable Energy Integration and Transmission Study:

Baseline: Current RPSs (2025: ~27.5% all renewables MN, ~1% SES MN, ~15% MISO)

Possible Study Scenarios ? (2030: 40% MN; 20% MISO; 2040: 50% MN, 25% MISO ?)

Note: Table conservatively assumes all renewables are variable wind and solar

9/7/13

2. Study Year & Models

Legislation calls for 2030 and later; Power system models are available for 2028 (PROMOD?, PSS/E) and 2018 (updated ERAG MMWG Dynamics).

division of energy resources
Minnesota Department of Commerce

Key Questions & Issues (continued)

3. Generation expansion / mix to be studied?

Results are sensitive to system generation portfolio assumptions. Should multiple generation scenarios be studied?

- Incorporate recent Integrated Resource Plans for MN utilities; generation announcements
- How will mix of conventional resources change with increasing levels of variable generation?
- If needed, should the generation mix be re-optimized with more system flexibility?

4. Transmission expansion / topology to be studied?

Study of regional integration impacts to the Bulk Electric System (BES); must also consider access to regional demand side flexibility; could consider potential impacts to the BES from aggregate distributed generation.

- Start with MISO MTEP-13 models (2028; include Multi-Value Portfolio lines)
- For additional transmission expansion, draw from:
  - MTEP Appendices for additional transmission expansion
  - MN RES Transmission Studies (2009 RES Update, Corridor, Capacity Validation)

division of energy resources
Minnesota Department of Commerce

Key Questions & Issues (continued)

5. **Range of possible impacts include:**

Must be prioritized & focused in order to complete study by November 2014!

   a. Operations
      - **Challenging time periods**: e.g. wind/solar sustained drop, rapid increase when thermal units are at minimum, ramping out of phase with load, etc
      - **Role of wind and solar forecasting**
      - **Impacts to thermal units**: turn around times for start-ups / shutdowns, thermal cycling
      - **Role of flexible resources (supply and demand side)**
      - **Reserve strategies**
      - Impacts of new reliability based control (BAAL - Balance Authority ACE Limit)
   b. Grid
      - **Transmission necessary for interconnection and delivery of renewable energy and for access to regional geographic diversity and regional supply and demand side flexibility**
      - **Short Circuit Levels**
        - Is the grid stiff enough and the synchronous system strong enough to support hours with greater than 50% non-synchronous generation
      - **Stability issues**
        - Transient stability during periods of high % non-synchronous generation
        - Frequency response, acceleration issues (?), large motor impact, distance from disturbance, impacts of using generic vs actual stability models for wind generators
      - System voltage issues
      - Aggregate DG issues
      - Smart grid infrastructure issues
   c. Markets
      - Assess system production cost
      - Congestion price exposure & delivery cost hedging from variable renewables

Key Questions & Issues (continued)

6. **Types of solutions to be identified and developed could include:**
   a. System operating and reserve strategies
   b. Improved system flexibility (physical capability, grid strength, market)
      - supply side resources
      - demand side resources (demand response, smart grid technologies, etc)
      - transmission
        - efficient use (e.g. dynamic line ratings and limits)
        - expansion (e.g. grid stiffness, interconnections to neighboring regions, etc)
        - system controls (e.g. damping from HVDC voltage source converters)
   c. Wind Plant Active Power Control (AGC, inertia response, primary frequency response)
   d. Market rules

7. **Basis for comparison?**
   What are the comparable impacts of other forms of generation, other loads, and other consumers of ancillary services?

8. **How can multiple study questions and issues be balanced and prioritized and focused in order to achieve a successful study schedule and budget?**
   - Address higher priority issues quantitatively and lower priority issues qualitatively?

Study options must be prioritized & focused in order to complete study by November 2014!

division of energy resources
Minnesota Department of Commerce

Draft Study Approach

Must be prioritized & focused in order to complete study by November 2014!

1. **Study Scenarios, Data Sets, and Models**
   - Capacity & siting for wind and solar
2. **Variability Analysis**
   - Load net wind/solar – ramp rates, seasonal & daily variations, etc
3. **Develop Conventional Generation Portfolios**
4. **Initial Transmission Expansion**
5. **Hourly Production Simulations**
   - Assess delivered renewable energy
   - Identify challenging time periods (ramp rate adequacy, minimum thermal generation, transient events, etc)
6. **Sub-Hourly Performance Simulations**
   - Assess reserve and ramp rate adequacy
7. **Transmission Grid Simulations**
   - Steady state power flow
   - Short circuit analysis
   - Dynamic Stability (transient, voltage, frequency)
8. **Update Transmission Expansion (if needed) & Gen Mix (if needed)**
9. **Assess Overall Performance**
10. **Identify and Develop Solutions**

division of energy resources
Minnesota Department of Commerce

Draft Study Structure

Tasks:

1. **Develop Scenarios, Data Sets, and Models**
   - wind/solar, load, generation, transmission, etc
   - production cost, power flow
   - stability (EI frequency & governor response base case?)

2. **Assess Impacts**

   Must be prioritized & focused in order to complete study by November 2014!

   a) **Variability Analysis**
      - load net wind/solar, etc
      - reserve requirements & strategies

   b) **Grid Analysis**
      - power flow
      - short circuit (screening?)
      - dynamic stability (transient, voltage, frequency – screening?)

   c) **Hourly Analysis**
      - determine curtailments, identify challenging time periods (min gen, high ramp rates, etc), assess system flexibility

   d) **Sub-Hourly Analysis**
      - reserves and ramp rate adequacy

   e) Markets
      - congestion price exposure (?), delivery cost hedging (?)

3. **Develop Conceptual Transmission Plan**
   - reliable system, access to regional geographic diversity and regional supply & demand side flexibility

4. **Identify and Develop Solutions**
   - mitigations, strategies

division of energy resources
Minnesota Department of Commerce

Minnesota Studies

Renewable Energy Standard Transmission Reports – Minnesota Transmission Owners

"Minnesota RES Update Study Technical Report." March 2009.

"Southwest Twin Cities – Granite Falls Transmission Upgrade Study Technical Report." March 2009.

"Capacity Validation Study Report." March 2009.

"RES Transmission Report." November 2007.

http://www.minnelectrans.com/reports.html

Dispersed Renewable Generation Studies – MN Transmission Owners

"Dispersed Renewable Generation Study – Phase II." Prepared for the Minnesota Department of Commerce Office of Energy Security, September 2009.

https://www.cards.commerce.state.mn.us/CARDS/security/search.do?method=showPoup&documentId={EBF556A0-8947-465E-B361-1A3ACF7E6FEE}&documentTitle=35425&documentType=6

Dispersed Renewable Generation Study Phase II Presentation, September 2009.

"Dispersed Renewable Generation Study – Phase I." Prepared for the MN Department of Commerce OES, June 2008.

http://www.uwig.org/DRG_Transmission_Study_Vol_I_061608045236_DRGTransmissionStudyVolI.pdf

Dispersed Renewable Generation Study Phase I Presentation, June 2008.

http://www.uwig.org/DRG_Webinar_Presentation_061608050119_DRGStudyPresentation-Webinar.pdf

2006 Minnesota Wind Integration Study – EnerNex and WindLogics

"Final Report – 2006 Minnesota Wind Integration Study, Volume I." Prepared for the MPUC, Nov 2006.

http://www.puc.state.mn.us/portal/groups/public/documents/pdf_files/000664.pdf

"Final Report – 2006 Minnesota Wind Integration Study, Volume II – Characterizing the Minnesota Wind Resource." Prepared for the Minnesota Public Utilities Commission, November 2006.

http://www.puc.state.mn.us/portal/groups/public/documents/pdf_files/000665.pdf

Wind Integration Study Presentation, December 2006.

http://www.puc.state.mn.us/portal/groups/public/documents/pdf_files/000666.pdf

2004 Xcel Wind Integration Study – EnerNex and WindLogics

"Xcel Energy and the MN Department of Commerce Wind Integration Study – Final Report." Sept 2004.

http://www.uwig.org/XcelMNDOCStudyReport.pdf

Wind Integration Study Presentation, September 2004.

http://www.uwig.org/XcelMNDOCStudyPresentation.pdf

Additional Studies

Utility Variable Generation Integration Group, Variable Generation Integration Library

http://www.variablegen.org/resources

division of energy resources
Minnesota Department of Commerce

Resources

Wind Integration

Ackerman, Thomas. *Wind Power in Power Systems.* New York: John Wiley & Sons. Second Edition. 2012.

DeMeo, Jordan, Kalich, King, Milligan, Murley, Oakleaf, and Schuerger. *Accommodating Wind's Natural Behavior: Advances in Insights and Methods for Wind Plant Integration.* IEEE Power & Energy Magazine, Nov/Dec 2007.

EnerNex Corporation. "Final Report – 2006 Minnesota Wind Integration Study." Prepared for the Minnesota Public Utilities Commission, November 2006.

GE Energy Consulting. "The Effects of Integrating Wind Power on Transmission System Planning, Reliability, and Operations, Report on Phase 2: System Performance Evaluations." Prepared for New York State Energy Research and Development Authority, March 2005.

Milligan, Porter, DeMeo, Denholm, Holttinen, Kirby, Miller, Mills, O'Malley, Schuerger, and Soder. *Wind Power Myths Debunked: Common Questions and Misconceptions.* IEEE Power & Energy Magazine, Nov/Dec 2009.

Milligan and Porter. *Determining the Capacity Value of Wind: An Updated Survey of Methods and Implementation.* WindPower 2008.

NERC Integration of Variable Generation Task Force (IVGTF). http://www.nerc.com/comm/PC/Pages/Integration%20of%20Variable%20Generation%20Task%20Force%20(IVGTF)/Integration-of-Variable-Generation-Task-Force-IVGTF.aspx

NERC Special Assessment: Interconnection Requirements for Variable Generation. September, 2012.

NERC Special Report: *Accommodating High Levels of Variable Generation.* April, 2009.

NERC 2012 *Long-Term Reliability Assessment.* November 2012.

Smith, Parsons, Acker, Milligan, Zavadil, Schuerger, and DeMeo. *Best Practices in Grid Integration of Variable Wind Power: Summary of Recent US Case Study Results and Mitigation Measures.* EWEC 2007, Milan, Italy. May 2007.

Wan, Y. "Wind Power Plant Behaviors: Analysis of Long-Term Wind Power Data." National Renewable Energy Laboratory, August 2004. (www.nrel.gov/docs/fy04osti/36551.pdf)

Wiser, R., Bolinger, M. *2012 Wind Technologies Market Report*. Lawrence Berkeley National Laboratory, August 2013. http://emp.lbl.gov/publications/2012-wind-technologies-market-report

International Energy Agency Task 25 Report: Design and operation of power systems with large amounts of wind power

http://www.ieawind.org/task_25.html

Utility Variable generation Integration Group

www.variablegen.org

NREL Wind Research
http://www.nrel.gov/wind/

division of energy resources
Minnesota Department of Commerce

Resources

Power Systems and Flexibility

Ela, Erik, Michael Milligan, and Brendan Kirby. *Operating Reserves and Variable Generation.* NREL 51978. August 2011

Eto, Joseph, John Undrill, Peter Mackin, Howard Illian, Carlos Martinez, Mark O'Malley, and Katie Coughlin. *Use of Frequency Response Metrics to Assess the Planning and Operating Requirements for Reliable Integration of Variable Generation.* LBNL-4142E. December 2010.

Hirst, Eric, and Brendan Kirby. *Allocating Costs of Ancillary Services: Contingency Reserves and Regulation.* ORNL/TM-2003/152

Holttinen, Hannele, Peter Meibom, Antje Orths, Mark O'Malley, Bart Ummels, John Tande, Ana Estanqueiro, Emilio Gomez, J. Charles Smith, and Erik Ela. *Impacts of Large Amounts of Power on Design and Operation of Power Systems; Results of IEA Collaboration.* Bremen International Workshop on Large-Scale Integration of Wind Power. Oct 2009.

International Energy Agency, *Harnessing Variable Renewables, A guide to the Balancing Challenge*, June 2011.

Lannoye, Eamonn, Michael Milligan, John Adams, Aidan Touhy, Hugo Chandler, Damian Flynn, and Mark O'Malley. *Integration of Variable Generation: Capacity Value and Evaluation of Flexibility.* IEEE. 2010.

Moura, John. *Keeping Reliability in Focus.* NERC Workshop on Accommodating High Levels of Variable Generation. April 2011.

Milligan, Michael, Pearl Donohoo, Debra Lew, Erik Ela, Brendan Kirby, Hannele Holtinen, Eamonn Lannoye, Damian Flynn, Mark O'Malley, Nicholas Miller, Peter Ericksen, Allan Gottig, Barry Rawn, Jasper Frunt, W.L. King, Madeleine Giescu, Emilio Lazaro, Andre Robitaille, and Innocent Kamwa. *Operating Reserves and Wind Power Integration: An International Comparison.* IEA Wind Task 25. 2010.

Milligan, Michael, Erik Ela, Bri-Matias Hodge, Brendan Kirby, Debra Lew, Charlton Clark, Jennifer DeCesaro, and kevin Lynn. *Cost Causation and Integration Cost Analysis for Variable Generation.* NREL/TP-5500-51860. June 2011.

Smith, J.C., Stephen Beuning, Henry Durrwachter, Erik Ela, David Hawkins, Brendan Kirby, Warren Lasher, Jonathan Lowell, Kevin Porter, Ken Schuyler, and Paul Sotkiewicz. *Impact of Variable Renewable Energy on US Electricity Markets.* IEEE. 2010.

Touhy, Aidan and Hugo Chandler. *Flexibility Assessment Tool: IEA Grid Integration of Variable Renewables Project.* IEEE. 2011.

Troy, Niamh, Eleanor Denny, and Mark O'Malley. *Base Load Cycling on a System With Significant Wind Penetration.* IEEE. 2010.

- IEEE Transactions on Power Systems
- IEEE Power Engineering Society Magazine, November/December 2005, 2007, 2009, 2011, 2013
- IEEE Wind and Solar Power Coordinating Committee
- Utility Variable Generaton Integration Group (UVIG): Operating Impacts and Integration Studies User Group, www.variablegen.org

division of energy resources
Minnesota Department of Commerce

Comments & Questions

Send comments on the study to:

REintegration.Energy@state.mn.us

Additional contacts:

Bill Grant
Deputy Commissioner of Commerce
Division of Energy Resources
Bill.Grant@state.mn.us
651-539-1801

Matt Schuerger
Technical Advisor to Commerce DER
MattSchuerger@esysconsult.com
651-699-4971

division of energy resources
Minnesota Department of Commerce